NEW REBUNCHERS FOR HIRFL-CSR*

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Abstract

Three almost-identical rebunchers have been designed for HIRFL-CSR. The first one B1 is going to be taken the off-line test and will be installed in place soon. The rebunchers B1 and B2 are in the BL1 beam line from the injector cyclotron SFC to the main cyclotron SSC, together for the longitudinal matching between the two cyclotrons. The rebuncher B3 is in the BL2 beam line from SSC to the main ring CSRm, either working at the stand-alone mode for the beam from SSC or at the combined mode together with B1 for the beam from SFC. They work at different harmonic modes depending on the beam energy to get the best matching effect. The rebunchers of 22~54MHz for B1 and B2 and 23.5~56MHz for B3 in frequency range and 20~120kV in amplitude use two tuning mechanisms, where the two movable capacitors are for low frequency end and the movable short-circuit panel is for high frequency end.

1 INTRODUCTION

HIRFL-CSR accelerator complex consists of two existing isochronous cyclotrons (SFC and SSC) and two under-constructing storage rings (CSRm and CSRe) [1]. The bunchers and rebunchers should be used between the stages of accelerators to make good matching of longitudinal phase space. Two linear bunchers (B01 and B02) [2,3] have been installed in the BL0 beam line (axial injection line to SFC) to group the continuous beam into bursts. Two rebunchers (B1 and B2) in the beam line BL1 between SFC and SSC have been redesigned and are under construction, as the old ones failed to work normally. The studies of the longitudinal motion showed that the defined parameters and the function modes should be also renewed. The third rebuncher B3 in the beam line BL2 between SSC and CSRm has been considered necessary. Considering that the beams from both SFC alone and SFC+SSC can be injected to the main ring CSRm [4], B3 has been designed almost the same as B1 and B2 in the first study (see Figure 1).

2 LONGITUDINAL MATCHING BETWEEN SFC AND SSC

2.1 Problems with the old rebunchers

The two old rebunchers B1 and B2 built in 1980's were manufactured in a rough way and have been proven to be

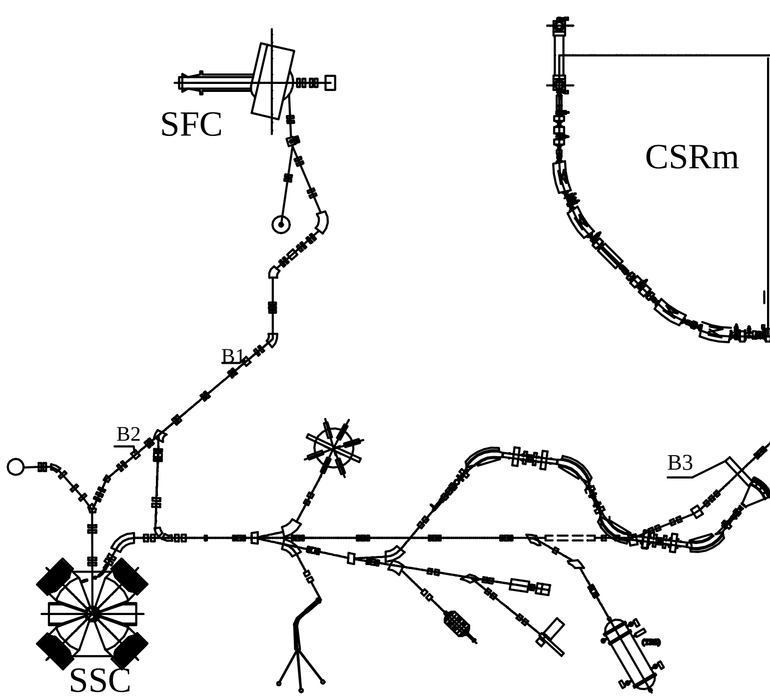

Figure 1, Rebunchers at HIRFL-CSR

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Table 1, Bunching Modes of the rebuncher in the BL1 beam line

Mode	h_1/h_2	h_B	f_B (MHz)	f_{RF1} (MHz)	E_1 (MeV/u)	$(\beta\lambda)_B/2$ (m)	f
1	1/2	6	33-54	5.5-9	3.48-9.32	0.392	1.972
2	3/2	2	26-33	13-16.5	2.16-3.48	0.392	1.972
3	3/4	2	22-28	11-14	1.55-2.51	0.392	1.972
4	3/4	3	22.5-33	7.5-11	0.72-1.55	0.262	1.729
5	3/6	3	22.5-28	7.5-9.33	0.72-1.11	0.262	1.729
6	3/6	4	22-30	5.5-7.5	0.39-0.72	0.196	-0.66

Note: h_1, h_2, h_B are harmonic numbers for SFC, SSC and rebunchers; f_{RF1}, E_1 for RF frequency and extracted beam energy in SFC; $(\beta\lambda)_B/2$ half wave length in the rebunchers; f for the effective voltage (see section 3.4).

impossible to be corrected. Main problems are the difficulty to start, the long-term stability and the narrow working range of 40~70kV. The rough manufacture of the cavity and the design of putting the 10kW power tetrode in the cavity were doubted to be the reasons.

2.2 New bunching modes and parameters for the new B1 and B2

Basing on the detailed studies of longitudinal matching between SFC and SSC, the new working modes have been designed to adapt the large beam energy range of 0.4~8.5MeV/u in BL1 beam line. For the high energy, high bunching voltage is needed and high harmonic number has been chosen. In the contrary, for the low energy, non-linearity of the bunching wave becomes important and low harmonic number has been chosen. The harmonic number now takes SFC-RF frequency as reference, compared with SSC-RF frequency in the past. The drift distance between the two gaps was chosen 0.35m. The bunching modes in the different cases are listed in table 1.

The main rebuncher B1 can work either in solitude or together with the auxiliary rebuncher B2. Since SFC and SSC do not have the same RF frequencies in most cases, B1 alone located in the middle of BL1 beam line makes the beam pulse length at the SSC entrance same as at the SFC exit, but they are different when transformed in SFC RF phase width and in SSC RF phase width. In most cases, we need to make compromise between the phase width and the energy spread at the SSC entrance to get the best transmission efficiency in SSC. The two rebunchers together can provide such flexibility. On the other hand, in the case of high energy, the two rebunchers together can ease the voltage requirement to B1.

The main parameters of rebunchers B1 and B2 are shown in table 2.

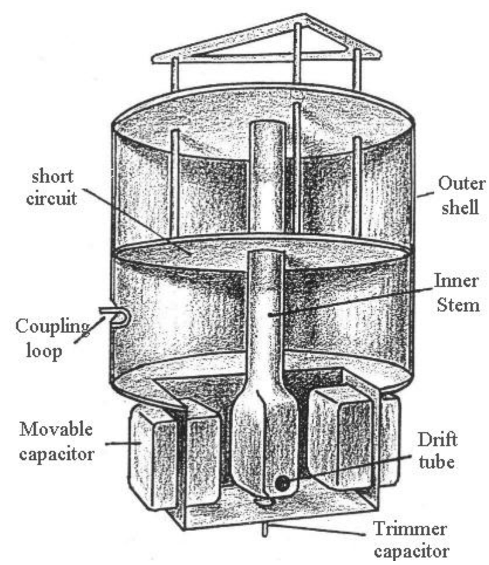

Figure 2 Schema for the B1 cavity

2.3 Energy compensation by B2

The auxiliary rebuncher B2 can be used as an acceleration cavity to adjust the beam energy in the cases of heavy ions where the stripper decreases the beam energy significantly. The energy match between the two cyclotrons is very important. The multi-turn extraction method used in SFC in the case of high energy gives also energy uncertainty. As the maximum available RF voltage from B2 is limited to 110kV, the maximum attainable energy compensation varies from 8% in the case of low energy to 0.5% in the case of high energy.

Table 2, Main parameters of the rebunchers B1 and B2

Cavity		Amplifier	
Frequency range	22~54MHz	Output RF power	40kW
Gap number	2	Open loop	$\Delta V/V \leq 1\times10^{-2}$
Max. Voltage amplitude	110kV@54MHz	Harmonics	-40dB
Frequency stability ($\Delta f/f$)	$<10^{-6}$	Output resistance	50Ω
Length of drift tube	350mm	Tetrode	TH571B
Harmonics	2, 3, 4, 6		
Gap	35mm		
Amplitude stability	$\pm1\times10^{-3}$		

2.4 Construction of the rebunchers B1 and B2

The construction of B1 has been just finished and is been taking offline test, both for cavity and amplifier. The installation to the place will be taken in two months later. Figure 2 shows the schema of B1 cavity. Once the offline test of B1 approves the design goal, the construction of B2 will be started. And the period of one year is needed for the work.

3 LONGITUDINAL MATCHING BETWEEN HIRFL AND CSRM

3.1 Injection to CSRm from SFC and SSC

As the main ring CSRm uses two kinds of injection schemes, one is to inject beam from SFC directly and the other is to use the combined SFC and SSC as the injector [4]. The former is very useful in the case of accelerating light ions, and the latter is necessary to get heavy ion beams of maximal energy from CSRm. So, the rebuncher B3 should be capable either to work together with B1 in the case of SFC-CSRm coupling or to work in solitude in the case of SFC-SSC-CSRm coupling. That defines the function modes and the parameters of rebuncher B3.

3.2 Working modes for the SFC-CSRm coupling

When CSRm takes SFC as its injector usually in the case of light ions, the required longitudinal emittance is to have a roughly erect ellipse after few turns injection and smaller momentum spread as possible. This is for the injection mode of multi-turn plus RF stacking plus electron cooling, whereas there is no such requirement for the injection mode of multiple multi-turns plus electron cooling.

As for the multi-turn injection, the drift lengths vary largely from the first turn to the last turn ($\frac{\Delta\phi}{2n\pi} = \frac{\Delta f}{f} = \eta\frac{\Delta p}{p}, \eta \approx \frac{1}{\gamma^2} - \frac{1}{Q_x^2}$, for CSRm, $\eta \approx 0.9$), smaller possible momentum spread is desired for the injected beam. This is to say, the rebunchers B1 and B3 act mainly like debunchers.

Due to the big difference in drift distances between the rebunchers and the matching points (L≈32m, 120m, 500m in order), B1 functions to keep the phase length within the linearity limits at B2 location (±90° with h_{B2}) as a weak rebuncher, and B2 functions like a debuncher to decrease the momentum spread. It is impossible to get a waist-waist transfer due to the big difference of drift distances. An example is given in Figure 3.

Since SFC usually works at h_1=1, and the rebunchers B1 and B3 have been chosen to work at h_{B1}= h_{B3}=4 for the energy range of 4.0-12MeV/u due to the limitation of B1 frequency range (see table 1) and the requirement for larger linearity range with the larger beam phase width of about ±20°. The available buncher voltage of 110kV in amplitude is enough for the both rebunchers.

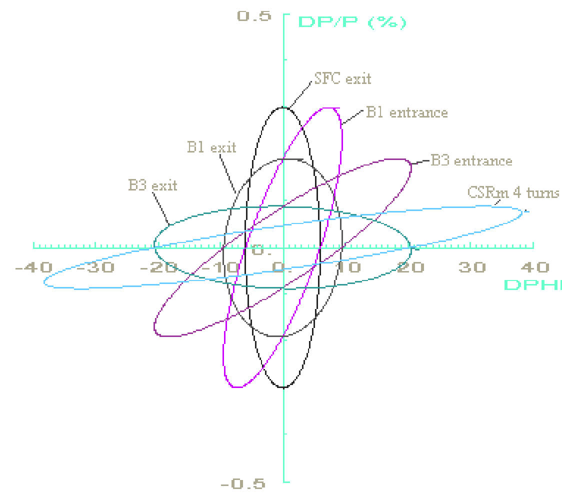

Figure 3 Phase ellipses with SFC-CSRm matching

3.3 Working modes for the SFC-SSC-CSRm coupling

In this case, only is the rebuncher B3 available, so the consideration is even simpler. As stated in section 3.3, there is no waist-waist transfer. To get a result of small phase width and small momentum spread in the CSRm (after 4 turns), the rebuncher B3 should rotate the beam ellipse to become slight convergent at its exit. An example is given in Figure 4.

Since SSC works at h_2=4 in the case of medium heavy ions and at h_2=6 in the case of very heavy ions, the calculations show that the frequency range 26~56MHz (h_{B3}=4 relative to SSC RF in the two cases) and the

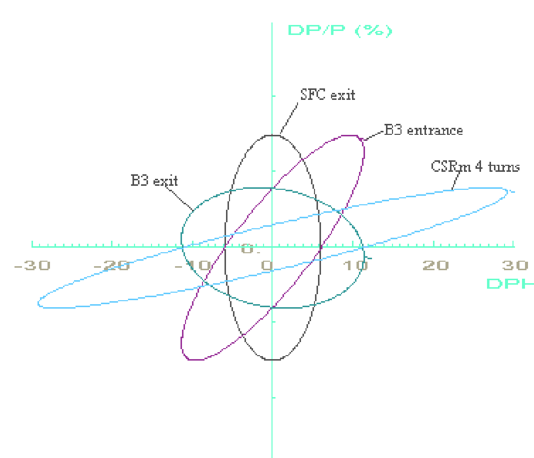

Figure 4 Phase ellipses with SFC-SSC-CSRm matching

Table 3, Bunching Modes of the rebuncher B3

Mode	h_i	h_{B3}	f_{B3} (MHz)	f_{RFi} (MHz)	E_i (MeV/A)	$\beta\lambda/2$ (m)	f	Injector
1	1	4	23.5-38.8	5.88-9.69	4.0-11.0	0.592	1.988	SFC
2	4	4	26.0-56.0	6.50-14.0	5.6-26.9	0.629	1.961	SSC
3	6	4	33.0-56.0	8.25-14.0	4.0-11.7	0.419	1.765	SSC

Note: parameters with subscript "*i*" for the injector.

amplitude voltage of 120kV are enough to meet the requirement of longitudinal matching.

3.4 Parameters for rebuncher B3

From sections 3.2 and 3.3, the parameters for the rebuncher B3 are slightly different from those of the rebunchers B1 and B2. The frequency range for B3 is slightly shifted to higher and the voltage amplitudes are almost the same. Since B3 should work with the beams come both from SFC (h_1=1) and from SSC (h_2=4 and h_2=6), the choice of the fixed length L_B of the drift tube is the compromise among the three cases. We chose L_B=0.55m, compared with L_B =0.35 for B1 and B2. Taking the bunching waveform $V_B = fV_m \sin\phi$, the parameters of B3 are shown in table 3. In keeping the structure of the rebuncher cavity same to B1 and B2, the B3 cavity has to be modified to fit the new L_B and the frequency range (23.5~56MHz). The amplifier for B3 has also slight modification from those for B1 and B2.

4 CONCLUSIONS

The three rebunchers have been designed to meet the requirement of longitudinal matching between the stages of HIRFL-CSR accelerator complex. Due to the multiple combination modes and the large acceleration range, all the three rebunchers should work in the different modes. They have been designed to have same structure with similar parameters. The frequency ranges of 22~54MHz for B1 and B2 and 23.5~56MHz for B3, and the voltage amplitude of 120kV at maximum for all the three are technical realizable. One of them is near to completion and the two others will be started after the commissioning of the first.

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